

THE PHOTOGRAPHIC METHOD OF STUDYING TRAFFIC
BEHAVIOR

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SYNOPSIS

This report presents a new method of securing accurate data on traffic behavior by means of pictures and illustrates the use of such data in the development of a new formula for expressing the relation between the number of vehicles passing a given point, their average speed, and spacing.

From the position of a vehicle in two or more pictures taken at short definite intervals of time its velocity and acceleration can be determined. A sixteen minute Simplex moving picture camera was geared for a constant time interval between exposures.

From 6,000 pictures of 794 vehicles the following expression for the spacing of cars whose speed is controlled by that of the leading car of a group was developed.

$$S = 21 + 1.1 V$$

wherein S is the distance center to center in feet between the vehicles and V is the velocity in miles per hour.

This paper presents a new method of securing the accurate data on traffic behavior which are necessary both for the design of streets and highways with adequate capacity and for the proper regulation of traffic. The method which involves the use of pictures taken at short, definite intervals of time on motion picture film was developed as the result of an investigation carried out during the past year as a University of Michigan Fellowship project. This Fellowship was granted by the Detroit Edison Company.

In the first part of the work, the writer had the cooperation of the Michigan State Highway Department which lent the assistance of Frank Olmstead, Assistant Research Engineer, who made valuable suggestions in connection with the development of equipment and the analysis of data. During the latter part of the study, the Dow Chemical Company of Midland, Michigan, sponsored and financed an investigation of the effect of road surfaces on vehicle speeds.

R. L. Morrison, Professor of Highway Engineering and Highway Transport, who directed the project has made many valuable suggestions as well as given indispensable and constructive criticism.

R. S. Swinton, Assistant Professor of Engineering Mechanics, has followed the work very closely throughout, given unsparingly of his time and has been especially helpful in developing the necessary technic.

The results of the study indicate that the average minimum spacing,

¹ This paper is a portion of a dissertation presented for the degree of Doctor of Philosophy in the University of Michigan.

center to center in feet, at which automotive vehicles travel, may be expressed by the formula, $S = 21 + 1.1V$, where S equals the spacing in feet, and V equals the velocity in miles per hour. If V is expressed in feet per second, $1.1V$ must be changed to $0.75V$. The coefficient, 0.75, is the brake reaction-time in seconds. Brake reaction-time is the time it takes an automobile driver to bring the brakes into operation after he has received a stimulus to do so. The data seem to indicate that the reaction-time may vary with driving conditions so as to give different spacings for city traffic and for the open highway. The photographic method of investigation may also be used to study practice in passing, the variation in the speed and number of vehicles on each lane of a multiple highway, the time lost by traffic interruptions, and the amount of traffic congestion on a highway.

The new method is described and its use is illustrated in the development of a new formula for expressing the relation between the number of vehicles passing a given point, their average rate of speed, and the average spacing at which they travel. A brief review of literature pertinent to the subject of speed and spacing is given before the development of the formula. After the development and discussion of the formula other traffic problems and the adaptation of the picture method to their solution are briefly outlined.

METHOD OF SECURING AND ANALYZING DATA

By taking pictures of vehicular traffic at short, definite intervals of time an instantaneous record of the position of the vehicles at the end of each interval can be obtained. From the position of a vehicle in each of two successive pictures its velocity may be found, and its acceleration from three or more. The spacing of cars in the same picture is evident. In case the following vehicle does not appear in the same picture, but in one at a later interval, the spacing may be fairly accurately determined from its velocity and the interval of time elapsing between the pictures in which the vehicles appear.

Field Method

The field method of securing data was quite simple. A 16 mm. Simplex movie camera was used to take the pictures. An electric motor driven by an automobile storage battery operated the camera with a constant time interval between exposures. Figure 1 shows the camera with the motor attachment. Varying the voltage by changing the battery terminals controlled the time interval, which might be varied from one-half to two seconds. This method was found better than rheostat control. The time interval was carefully measured with a stop watch over a period of 40 to 100 exposures and checked by the sweep hand of a photographic timer included in the pictures. In order that moving cars might appear in at least two consecutive pictures a

field of twice the space traveled per time interval was required. To avoid photographic blur due to motion, a moving car had to be at least 300 feet from the camera. In this case the length of road included in a picture was about 125 feet. The blur might have been lessened by using a faster shutter. At the beginning of each film, and hourly during a run, there was included a photograph of a bulletin board

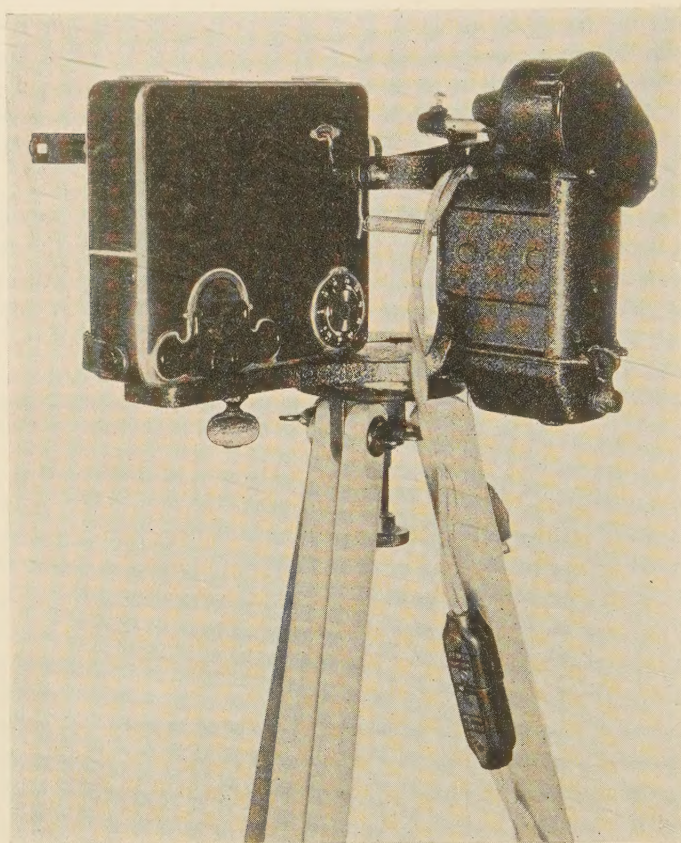


Figure 1. Camera with Motor Attachment

giving the location, date, hour, time interval, shutter opening and other pertinent information.

The white cloth stretched along the opposite side of the road in Figure 2 was used to keep the vehicles from fading into the dark background. Figure 3 shows three frames of pictures taken with the movie camera at this station. The vertical lines are added to show how the pictures look when projected upon a screen with lines drawn upon it for scaling distances.

The measured distance from the camera to the road together with



Figure 2

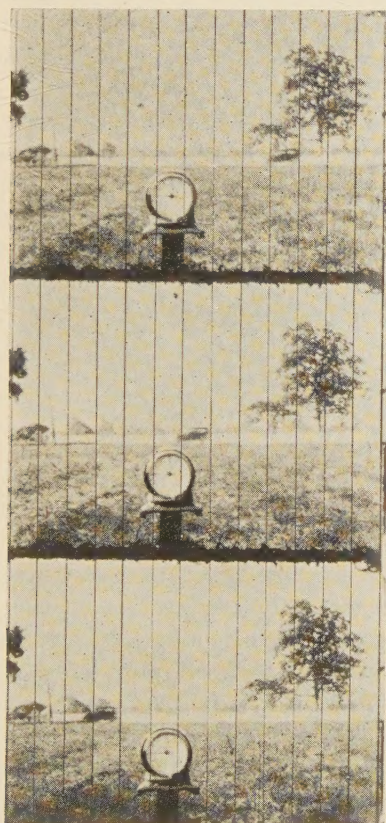


Figure 3

the camera characteristics suffices to give the scale of dimensions which are more accurately determined if the camera is set at right angles to the road. As a check, however, a complete plan of the section of the roadway studied is recorded giving the distances from the camera and between objects in the pictures such as fence posts or poles. Where no identification exists a 100 foot tape is laid along the pavement and at every 10 foot interval a marker is held over the point and photographed. There is thus obtained a definite scale for the picture.

Method of Analysis

The process of analysis consists of two parts; first, the pictures are projected upon a white screen ruled with parallel markings and the throw of the lantern is adjusted so that these divisions will represent five or ten foot intervals along the roadway in the picture, and second, the distance of travel or speed and the spacing between cars is taken from two pictures, projected upon the screen at the same time. In order to obtain a traffic flow curve for the highway the time may be read from the timer photographed.

The method of studying the pictures may be illustrated from Figure 4. In the first picture at the top the rear car is at point 9 of the scale and 55 feet behind the car in front, measured from front to front of car. In the second picture 0.80 of a second later, it has advanced to point 50 on the scale or has traveled 41 feet. Reduced to miles per hour this is 34.9. By reading the scale in the third picture it is found that the speed of the car is practically uniform; that is, there is no acceleration. To facilitate reading in case accelerations are not wanted, the projection lantern may be mounted on a thin board secured in place by a center pin so that the board and projector may be easily turned to the right or left to bring the car in the first picture to zero on the scale and thus the distance the car has moved, or speed, may be recorded directly in the place of the station.

RELATION OF THE SPEED AND SPACING OF VEHICLES

Data secured by the picture method make possible also the derivation of a formula which expresses in a useful way the relation between the number of vehicles in a lane passing a given point, their velocity and the average minimum spacing at which they travel. Other valuable studies have been made to determine this relation but it is believed that they have not been based upon as accurate data as it is possible to secure by the picture method. It may be reasoned, logically, perhaps, that the driver of an automobile maintains a sufficient spacing between his own car and the one ahead to be able to stop should the first car meet with disaster, but whether he does or not can be found only by observations such as are possible with the photographic method.

A review of the literature on the subject of speed and spacing is included for the purpose of comparison and for aid in the interpretation of new data.

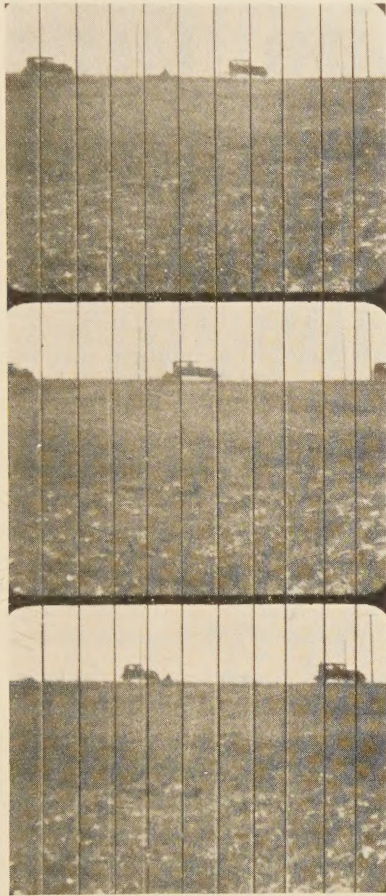


Figure 4

A. N. Johnson's Investigations

A. N. Johnson, Dean of Engineering at the University of Maryland, derived a formula based upon the idea that cars should maintain a sufficient distance from the car in front for bringing the car to a stop. The formula is as follows:

$$N = \frac{5280 V}{15 + \frac{V^2}{15}}$$

In this formula N is the number of vehicles per hour passing a given point at a velocity of V miles per hour with an average car length of 15 feet, and $\frac{V^2}{15}$ is the clearance between the cars. This formula was widely accepted. Dean Johnson afterwards, however, (1928)¹ from data obtained from airplane pictures, changed the clearance to vary as the $4/3$ power of the velocity. This gave the maximum discharge at 34.5 miles per hour as compared to about 15 miles in the first instance. This is shown by the curves in Figure 7. The velocities were obtained from the velocities of cars traveling with the traffic and, from the fact that, since adjacent photographs overlapped, the same group of pictures appeared in two succeeding pictures, displaced by the distance that they had traveled between exposures. The author states that as the scale of the different photographs varied somewhat, as well as the interval between exposures, the results would be expected to show a like variation in accuracy. One hundred and twenty-seven pictures were taken.

Sigvald Johannesson's Investigations

Sigvald Johannesson² derived a formula based upon "certain observations" of the "Relation of Rate of Speed to Spacing of Vehicles" as follows:

Rate of speed miles per hour	Spacing center to center of vehicles in feet
3.0	33
5.0	42
9.5	45
12.0	50

From this he deduced that the "spacing is guided by a certain fixed length, say five feet, plus a time interval, which judged by the recorded vehicle spacings noted above, may be taken to be 1.5 seconds." In other words, the minimum open space between two motor vehicles traveling at a certain rate of speed may be taken to be five feet plus the distance the vehicles will travel in 1.5 seconds at that rate of speed. The equation he then uses for the maximum density of traffic is as follows:

$$N = \frac{5280L}{2.2V + 25}$$

¹ Maryland Aerial Survey of Highway Traffic Between Baltimore and Washington, By A. N. Johnson, Proceedings of Highway Research Board, Vol. 8, page 106.

² Highway Economics, by Sigvald Johannesson. Pub. 1931 McGraw-Hill, page 88.

in which N equals maximum density in number of vehicles per hour and V is the velocity in miles per hour. According to this equation, the density increases with the rate of speed and converges toward 40 vehicles per minute as a maximum. This is shown in Figure 7.

N. W. Dougherty's Investigations

Professor N. W. Dougherty, of the University of Tennessee, has evolved an equation³ for road capacity under the assumptions that all vehicles move in a lane at uniform speed and that they travel at a distance apart to prevent collision if a vehicle in front meets with disaster. Three factors are taken into consideration:

- (a) overall length of vehicle and clearance, 15 feet;
- (b) braking distance, $s = 0.0259 V^2$, where s = stopping distance in feet and V = speed in feet per second
- (c) time elapsed from the instant in which the driver observes the disaster ahead until he can apply his brakes. This time is assumed to be 0.5 second.

This gives a reaction distance of $d = 0.5 V$. Reducing this to give N , the number of vehicles which can pass a point in one hour at a velocity of V miles per hour, there results the equation:

$$N = \frac{5280V}{15 + 0.0556 V^2 + 0.75 V}$$

The curve for this equation is shown in Figure 7.

The Personal Equation in Automobile Driving⁴

In many fields of activity the presence of the so-called personal equation has been definitely established, and due allowance made for it. In few occupations is the existence of the personal equation more evident than in that of automobile driving. F. A. Moss and H. H. Allen in 1925 carried out an investigation of the personal equation in driving.

The object of the tests was to determine:

- (a) the average time that elapses between the hearing of a signal, such, for example, as the shot of a pistol, and the applying of the brake.
- (b) the relation between the reaction-time and the variability of the individual.
- (c) the effect on reaction-time of such factors as the speed of driving, training, age, sex, race, and general intelligence.

³ Roads and Streets, Vol. 70, Sept. 1930, Page 319.

⁴ *The Personal Equation in Automobile Driving*, F. A. Moss and H. H. Allen, Transactions of the Society of Automotive Engineers, 1925, Part I, Pages 497-510.

To carry out these experiments, apparatus was devised that consisted of two revolvers mounted securely on the underside of the running board of an automobile and pointed downward toward the road. One revolver was fired by the experimenter as a signal, and the other by the person under test in making the initial motion of applying the brake-pedal. Shells loaded with red lead were employed, so that when each gun was fired, a bright red spot was made upon the road. The reaction-time was determined from the speed of the car and the distance between the red spots on the pavement. The speed of the car was accurately measured by a chronometric tachometer.

The average reaction-time for the 57 drivers tested was 0.54 second. The variation was from 0.31 second to 1.02 seconds for different drivers. The authors state, however, that owing to the high intelligence of the subjects tested, probably many drivers could be found who might have reaction-times as long as 1.5 or even 2 seconds.

The experiment showed that:

- (1) The reaction-time is not appreciably changed with different speeds.
- (2) The reaction-time varies little with age and sex.
- (3) Persons of a high intelligence seem to have a shorter reaction-time.
- (4) Persons who have a shorter reaction-time show the least variation in different tests.
- (5) The reaction-time may be reduced by training; the reduction, however, in some men must stop far short of that in others.

Selection of Data

An attempt was made in the investigation of speed and spacing of vehicles to take only such observations as would show vehicles with a speed controlled by the vehicle in front. It is quite evident on a heavily traveled highway where the tendency of traffic is to bunch up, that the speed of the vehicles in the group is controlled by the leading vehicle. When the vehicles are traveling at a higher speed and at greater distance apart it is harder to determine whether the speeds are affected by congestion. It was decided to take pictures only of groups of vehicles which seemed to be driving at controlled speeds and to throw out all observations where the relative velocity of the leading vehicle differed by more than five feet per second with the one following.

Following the method illustrated in Figure 4, about 6000 pictures of both urban and rural traffic comprising 794 vehicles were studied to secure the information used in the derivation of the formula. The observations of spacing for each two mile variation in velocity, shown in the chart on page 391 when averaged and plotted in Figure 5, seem to be fairly well represented by the straight line equation:

$$S = 21 + 1.1 V$$

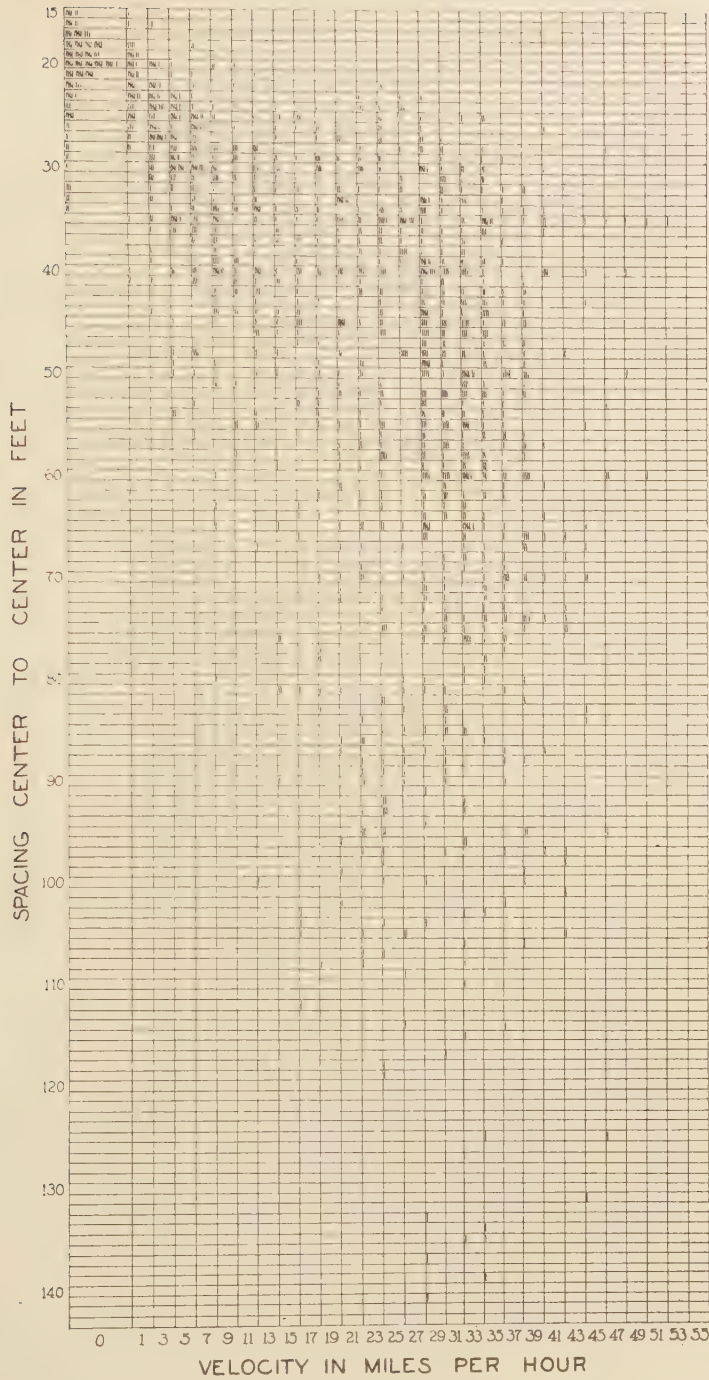


CHART SHOWING VELOCITY, SPACING, AND
NUMBER OF OBSERVATIONS

where S equals the spacing of vehicles, center to center, in feet, and V equals the average velocity in miles per hour.

Rationalizing the Equation

It was felt that the equation should contain terms for:

- (1) the spacing of cars with a velocity at or approaching zero;
- (2) an allowance for the distance traveled during the reaction-time of the driver; and,
- (3) possibly a term which would take account of the caution or judgment of the driver.

Since the spacings of groups of cars waiting for stop-lights to change had been observed to be from 20 to 22 feet, center to center, giving

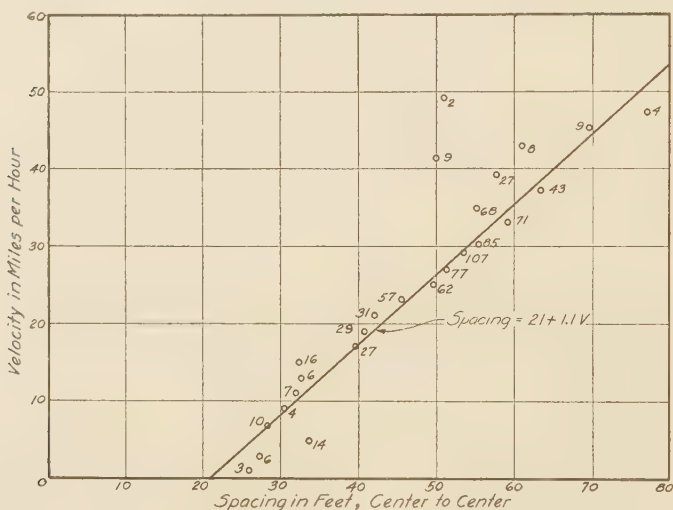


Figure 5. Speed and Spacing of Vehicles. The numbers show the observations for each point.

about a five foot clearance, the first term of the equation, 21, was assumed to be the spacing in feet at zero velocity.

The average reaction-time of 0.54 seconds, found by Moss and Allen, to a stimulus of sound was multiplied by $4/3$ to give 0.72 second as the approximate brake reaction-time to a sight stimulus.⁵ If the velocity, V , in miles per hour is changed to feet per second the coefficient, 1.1, becomes 0.75, which agrees closely with 0.72, the reaction-time in seconds.

The third term is apparently non-existent. The data, however, comprised in the 794 observations are admittedly lacking both for high and for low speeds. Additional observations of about 500 vehicles, to give a total of 1341 observations are shown in Figure 6. It is noted

⁵ Willard Lee Valentine, *A Psychology Laboratory Manual*, page 41.

that the data for slow speeds from zero to about 15 miles per hour, taken from city traffic, seem to determine a line whose equation is

$$S = 21 + 1.40 V$$

where V is expressed in miles per hour.

This means that reaction-time may be modified by driving conditions or else that the driver, using his judgment, allows himself longer time to react. The amount of this variation in reaction-time can be shown only by further study based upon new data.

The equation means that the variation in the minimum spacing between vehicles depends entirely upon the reaction-time of the driver. Since the negative acceleration of an automobile after the brakes have been applied is practically constant, a car will not collide with the one

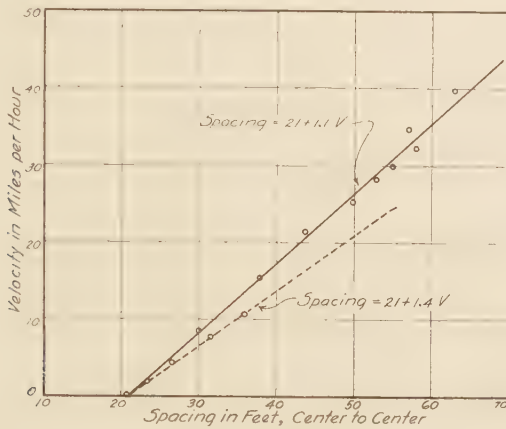


Figure 6. Speed and Spacing of Vehicles. The point of zero velocity is the average of 143 observations. Each of the other points is the weighted average of 99 observations.

ahead if the brakes are being applied on both cars and if both cars were traveling at the same speed before the brakes were applied. A graphic comparison of this formula with those of several other investigators is shown in Figure 7. The number of cars passing over a highway increases with higher velocities so that the theoretical capacity of a highway is increased by one-third if the average speed of all vehicles passing over it is raised from 20 to 40 miles per hour. This is an argument for a minimum speed regulation on congested highways.

Additional Data on Reaction-Time

It was decided to run a check test of brake reaction-time using a sight stimulus. Two cars were parked, one about fifty feet behind the other. A chronoscope reading to thousands of a second was wired in circuit with the tail light of the front car and the brake pedal of the

rear car, so that it would measure the time from the coming on of the tail light and the pressing of the brake pedal.

Each person tested for reaction-time was told to remove quickly his foot from the accelerator pedal when he saw the light flash and push down on the brake pedal as if he were stopping the car. Each person made six or more trials.

The average time of 13 individuals tested on one car was 0.86 second, and the average of 27 individuals on another car was 0.74 second.

These results agree very closely with the 0.75 second arrived at in the speed-spacing formula, and serve to confirm the conclusion that the coefficient of V in the formula is the brake reaction-time.

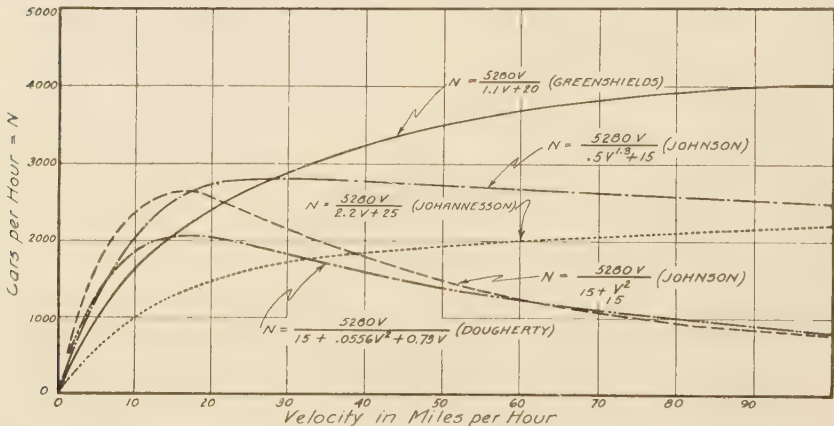


Figure 7. Graphic Comparison of Formulas for Determining the Relation Between the Number of Vehicles Passing a Given Point and Their Rates of Speed.

Significance of the Findings

The spacing between the cars at various speeds is less than has formerly been supposed. It is controlled by the reaction-time of the driver. This reaction-time may perhaps not be the same at all times for the same individual. It is indicated that the reaction-time may be greater in city traffic or else that the driver allows himself more time to react, which amounts to the same thing as far as performance is concerned.

Since the two cars tested showed an average difference of 0.2 second in reaction-time for four individuals tested on both cars, the importance of a convenient location of the brake pedal in reference to the accelerator becomes apparent.

OTHER PHASES OF TRAFFIC BEHAVIOR FOR STUDY

There are other phases of traffic behavior that could be studied with profit. Sufficient work has been done to show that solutions of the problems involved are possible.

Passing Practice. At what speeds do cars pass each other? What space and time do they require to pass? Under what conditions do drivers undertake to pass? Pictures taken of a long vista of highway such as could be obtained from a high promontory across a valley should give ideal data on this problem.

Amount of Congestion. Congestion starts at the point where the density of traffic is such as to retard its average speed.⁶ As long as cars can freely pass each other there is no congestion.

The amount of congestion can be found by first determining from freely moving cars, say those over 125 feet apart, the average speed on the highway when it is uncongested. The average speed of vehicles for different densities of traffic will then show the amount of congestion. If the average free speed on a highway is 45 miles per hour, a speed of 40 miles per hour for a certain density shows an average loss of five miles per hour per vehicle or a congestion of $\frac{1}{9}$. The composition of traffic should be the same in order to give a true comparison for the average speed of trucks is different from the average speed of passenger cars.

Stop-Light Practice. What is the total time loss for timed signals and how does this vary with different traffic densities? A study of traffic-actuated signals should be included. Observations of over one thousand cars have been tabulated and a tentative formula, based upon the average acceleration practiced by drivers at stop-lights, has been developed to show the time lost by traffic interruptions.

Speeds Attained Under Different Limitations. How are speeds related to types of roadway surface, to block lengths, to parking systems, to street widths and to lane of travel? Does lane marking on city streets speed up traffic? In the part of the work sponsored by the Dow Chemical Company, 341 cars passing over a certain section of concrete road from 11 A.M. to 5:30 P.M. had an average speed of 47.8 miles per hour. During the same time 64 trucks maintained an average speed of 37.9 miles per hour. On another day 146 cars had an average speed of 47.7 miles per hour. The average speed of 416 cars on a gravel road was observed to be 32.6 miles per hour and of 39 trucks 28.2 miles per hour. The weather was dry during the observations and there was no congestion. Further studies along this line should be made.

Traffic Surveys. A device whereby the camera will be operated by a solenoid actuated by a photoelectric cell should be of great aid in getting rather complete traffic information. Counting devices operated by the photoelectric cell have already been used successfully. The pictures would show the types of vehicles, their speeds and the times of day at which they passed. This information for each car would all appear on one picture since the timer included in the picture would show the time of day while the distance the car had traveled during the

⁶ Proceedings of the Highway Research Board, Vol. 6, page 218.

small delay from the time it cut the ray of light falling on the cell and the snapping of the camera would show its speed. Given the speed of all vehicles and the number passing in any period of time it becomes possible to show the amount of congestion or speed retardation during that period. Such a device is now being developed under the direction of Professor Swinton.

Not all of the possible uses of the photographic method of investigating traffic behavior have been listed, but its potentialities are evident.

This type of study will give pictorial records which should make valuable information available to those concerned in the design of vehicles and the design and maintenance of highways.

